ERDC/CRREL TR-15-1

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

Bearing Capacity of Floating Ice Sheets under Short-Term Loads

Over-Sea-Ice Traverse from McMurdo Station to Marble Point

Jason C. Weale and Devinder S. Sodhi

January 2015

Photo: Steve Zellerhoff, USAP Traverse Operations

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Under Engineering for Polar Operations, Logistics, and Research (EPOLAR)
EP-ANT-13-49, "Safe Sea Ice Thickness for Vehicle Travel"

Abstract

The United States Antarctic Program's Antarctic Infrastructure and Logistics Program within the National Science Foundation's Division of Polar Programs operates an over-sea-ice traverse from McMurdo Station to routinely resupply Marble Point Camp. The traverse requires that heavy tractor trains travel over large segments of sea ice that can contain both narrow and wide leads (cracks).

For this effort, we determined the ice thicknesses required for the resupply traverse to safely operate on both cracked and un-cracked (infinite) ice sheets during each of the four periods of sea-ice temperatures at McMurdo Station. Results presented in this report are valid for first-year sea ice only, and we recommend that the Marble Point Traverse stays clear of regions where there is an isolated multi-year floe embedded in first-year ice. Our analyses considered a 41,000 lb Caterpillar Challenger 95E tractor with attached Fassi crane towing a single 3000 gal. steel tank sled full of fuel (32,370 lb). Wide leads require use of a bridge, and thus we also consider the load case where a 9208 lb bridge is used to cross open leads up to 13 ft wide. We derived our results from a combination of finite element analysis (ice with leads) and closed-form solutions (semi-infinite and infinite ice sheets).

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Preface

This study was conducted for the National Science Foundation, Division of Polar Programs (NSF-PLR), under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-13-49, "Safe Sea Ice Thickness for Vehicle Travel." The technical monitor was George Blaisdell, Chief Program Manager, NSF-PLR U.S. Antarctic Program.

The work was performed by Jason C. Weale (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief) and Dr. Devinder Sodhi (retired), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). Dr. Sodhi's temporary appointment is part of the Knowledge Preservation Program, Oak Ridge Institute for Science and Education. At the time of publication, Dr. Lindamae Peck was Acting Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

COL Jeffrey R. Eckstein was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms and Abbreviations

AIL	Antarctic Infrastructure and Logistics Program
CRB	Cape Roberts Bridge
CRREL	Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations Logistics and Research
ERDC	U.S. Army Engineer Research and Development Center
MPT	Marble Point Traverse
NSF	National Science Foundation
NZAP	New Zealand Antarctic Programme
PLR	Division of Polar Programs
USAP	United States Antarctic Program

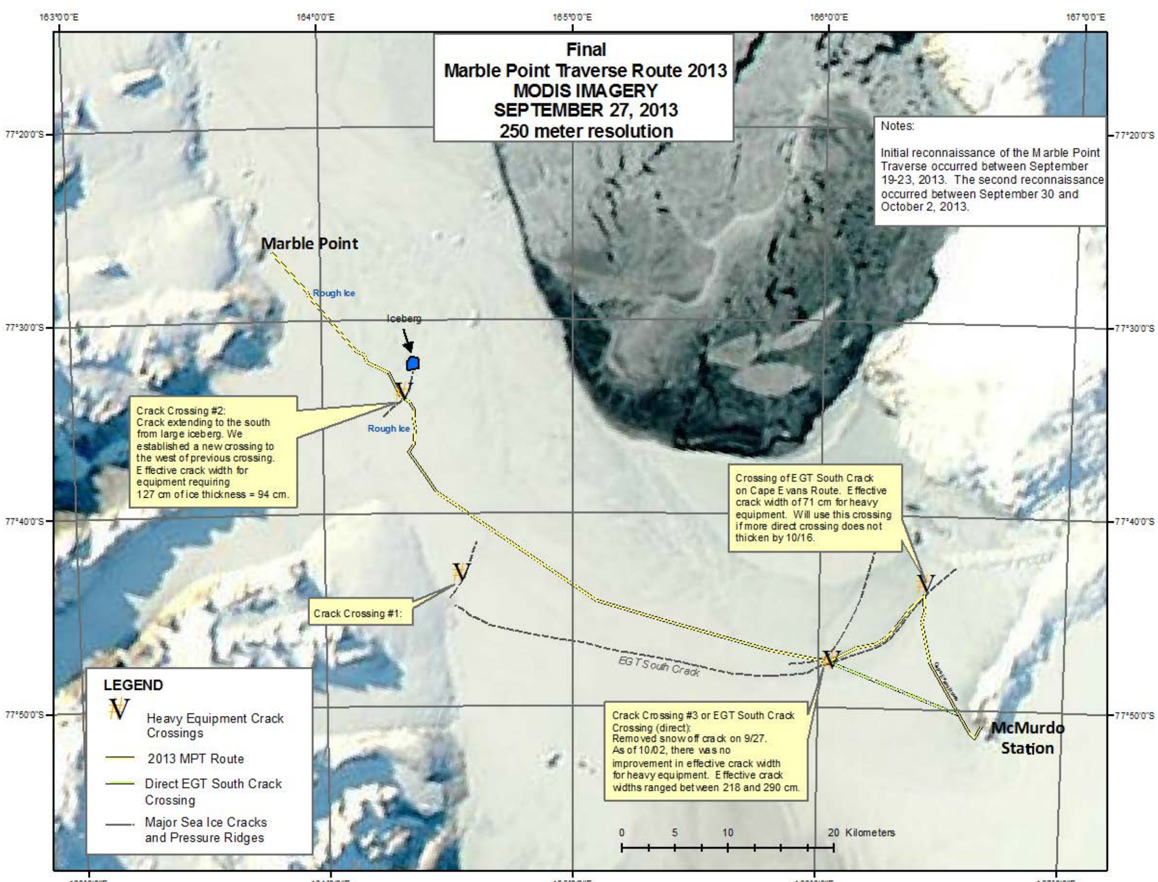
Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms

1 Introduction and Background

The United States Antarctic Program's Antarctic Infrastructure and Logistics Program (USAP-AIL) within the National Science Foundation's Division of Polar Programs (NSF-PLR) conducts resupply activities for Marble Point from McMurdo Station via an over-ice traverse. NSF, their prime contractor, and CRREL establish the route across the sea ice of McMurdo Sound (Figure 1) prior to each traverse. The traverses typically happen annually or less frequently.

Figure 1. McMurdo-Marble Point Traverse Route 2013. (Image courtesy of Jennifer Erxleben, Antarctic Support Contractor.)



Marble Point Camp functions primarily as a refueling depot and staging location for helicopter operations in the McMurdo area Dry Valleys. The resupply effort delivers large quantities of fuel by using agricultural tractors towing 3000 gal. (U.S.) steel tank sleds. Because of the variability of the sea-ice conditions in McMurdo Sound, the route may consist of both first-year and multi-year ice that contains cracks, or *leads*. Ice strength properties are functions of its temperature and thickness. Planning for safe travel on sea ice depends on establishing the minimum required ice thicknesses to support traverse loads for infinite (no cracks) and semi-infinite (cracked) ice conditions. Primarily, ice temperatures govern ice properties; and previous works (most recently Bjella and Weale [2012]) note the temperature conditions traditionally used to define the four periods of ice conditions in McMurdo Sound throughout a calendar year. Period 1 is the coldest and Period 4 is the warmest. The Marble Point Traverse (MPT) targets operations near the end of Period 1 (October, which is late winter/early spring in McMurdo) when the ice is cold, thick, and strong.

The objectives of this report are to establish safe MPT sea-ice-crossing criteria for non-cracked ice and for ice with small cracks. This report also addresses the safety requirements for using a steel-girder, timber-deck bridge to enable the tractor-tank sled combination to travel over a lead that is otherwise too wide to cross. In 1995, the Works Consultancy Services of Christchurch, NZ, designed the Cape Roberts Bridge (CRB) for the New Zealand Antarctic Programme (NZAP). NZAP provided USAP with a double cut sheet design representing the CRB plan and section detail for use in this assessment (Appendix A). Bridge dimensions and weight estimates used in this report were derived from the cut sheets.

2 Safety Methodology for Sea Ice

The standard for safe operation and transportation on a floating ice sheet is to limit the load such that (a) the maximum tensile stress in the ice sheet is below an allowable stress for ice and (b) the short-term and long-term deflections of the ice sheet are less than the available freeboard, which is taken to be 8%–10% of the ice thickness. The reason for the first criterion is to prevent formation of cracks in an intact ice sheet, and the second criterion prevents flooding of the top surface of ice sheet. For decades, these two criteria have been used to plan successful landing and parking of aircrafts on floating ice sheets near McMurdo, Antarctica (Katona and Vaudrey 1973; Katona 1974; Vaudrey 1977).

To comply with the first criterion, one must calculate the maximum tensile stress induced by a load, or a series of loads, from an elastic analysis of an intact floating ice sheet (Hertz 1884; Westergaard 1926; Wyman 1950; Nevel 1965, 1976); and this stress is limited to an allowable stress for different temperature regimes of the ice surface. As noted above, these temperature regimes are referred to as *periods*. Table 1 lists sea-ice surface temperature, allowable stress, and effective elastic modulus for the four periods; and we use these values in our calculations. Essentially, to develop safe-crossing criteria, we seek in each period the minimum ice thickness that can support the applied loads. Prior to commencing a traverse, an advanced field party can measure the ice thickness to compare against the results presented in this report and determine whether or not the safe minimum thickness exists for the operational period. These comparisons will aide in making go/no-go decisions.

Table 1. Material properties of sea ice (Vaudrey 1977; Barthelemy 1992).

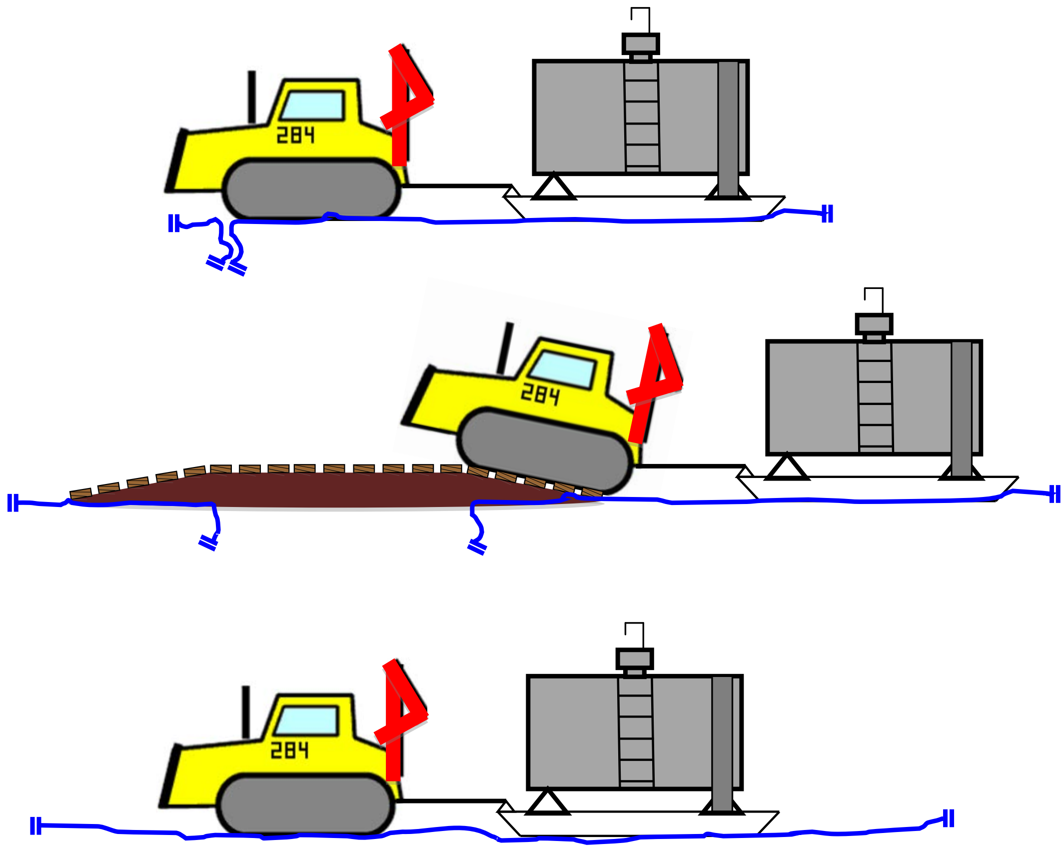
Period	Ice Surface Temperature (°C)	Flexural Strength (psi)	Allowable Stress (psi)	Allowable Stress (kPa)	Elastic Modulus (GPa)
1	≤−27	70	49.0	338	4.1
2	−27 < x ≤ −20	62	46.5	321	2.7
3	−20 < x ≤ −10	58	43.5	300	1.7
4	−10 < x ≤ −4	40	30.0	207	1.1

3 Traverse Configuration and Load Case Development

Design methods for determining the minimum required ice thickness and maximum allowable ice temperature for known load cases have not been formulated for easy calculation; and thus, ice safety parameters are typically developed on a case-by-case basis after calculating the magnitude of the applied loads and comparing them against ice properties derived from empirical data contained in the literature cited for this report. After consulting with AIL and the Antarctic Support Contractor, we determined that the heaviest possible (worst case) load configuration approaching a lead during the 2013 MPT would be a Caterpillar Challenger 95E tractor with an attached Fassi crane (41,400 lb combined weight) towing a single 3000 gal. steel tank sled full of fuel (32,370 lb). Weale and Lever (2008) previously calculated the loads and corresponding ground pressures for these implements.

Because the loads on a floating ice sheet considered here are the weights of a tractor and a tank sled, which may have to cross leads in an expanse of a large floating ice sheet, we consider here two lead-crossing cases: Case 1, a narrow lead, and Case 2, a wide lead. While it is possible to cross a narrow lead without a bridge, a wide lead may require a CRB. In both cases, the load is considered to be at the edge of a semi-infinite ice sheet as that location causes maximum deflection and maximum tensile stress. The design load for crossing a narrow lead consists of the weight of the tractor and the tank sled, and the design load for crossing a wide lead consists of the weights of the tractor and the tank sled plus half of the weight of the CRB (4604 lb). The governing load configuration at a narrow lead is when the leading edge of the tractor tracks is at the edge of the crack. Correspondingly, for a wide lead requiring use of the CRB, the governing load configuration is when the tractor weight and half of the CRB load are assumed to act on the same half of the lead as the tank sled in tow behind the tractor. That is, the entire tractor load is acting on half of the bridge as represented in Figure 2. In addition to the semi-infinite ice sheet load cases, we also determined the minimum ice thickness required for the tractor and tank sled pair to operate on an infinite (no leads) ice sheet: Case 3. Figure 2 presents sketches for all three-load cases.

Figure 2. Illustrations for load cases 1, a narrow crack (top); 2, a wide crack (middle); and 3, an intact sheet (bottom).



The CRB is 33 ft long and designed for a maximum central (clear) span of 13 ft; has a design capacity for a single axle load of 66,000 lb; and the main beams have a minimum yield stress of 36 ksi.* The rounded ends of each girder reduce the on-ice bearing length of the end-spans from 10 ft to 8 ft. Thus, our calculations for the wide lead (load Case 2) use an effective bearing footprint of 8 ft long × 1 ft wide for the ends of each bridge girder. Note that a structural evaluation of the CRB was not within the scope of this project.

* M. Reed (Lockheed Martin Antarctic Support Contract), 2013, email correspondence regarding Cape Roberts Bridge design specifications originated from Paul Woodgate, Logistics Team Leader for Antarctica New Zealand. Works Consultancy Services of Christchurch, NZ, ca. 1995, originally designed the Cape Roberts Bridge.

4 Evaluating Traverse Loads at the Edge of a Semi-Infinite (Cracked) Ice Sheet

The load distributions for the two semi-infinite ice sheet cases defined above are labeled as 1 (without a bridge) and 2 (with a bridge) and are shown below in Figures 3 and 4, respectively. Table 2 lists the contact area and its associated ground pressure for the two load distributions. Maximum tensile stresses caused by each load distribution are at the bottom edge of the ice sheet in the middle of each tractor tread (or in the middle of each girder in contact with the ice for load Case 2). The load of the tank sled and its distance from the edge of the ice sheet are about the same in both load distributions, thus it contributes the same amount towards maximum tensile stress in each load case. In load Case 2, there is an extra load due to the half weight of bridge. Coupled with the narrow steel bridge girders in contact with the snow at less than half the area of the tractor track (14 × 100 in. vs. 30 × 108 in.), the bearing pressure almost triples over load Case 1 (Table 2). This yields higher tensile stresses for load Case 2 than those for load Case 1.

Figure 3. Load Case 1 (ice edge at y = 0). Note that tractor footprints are represented in black, and the tank sled's are in red.

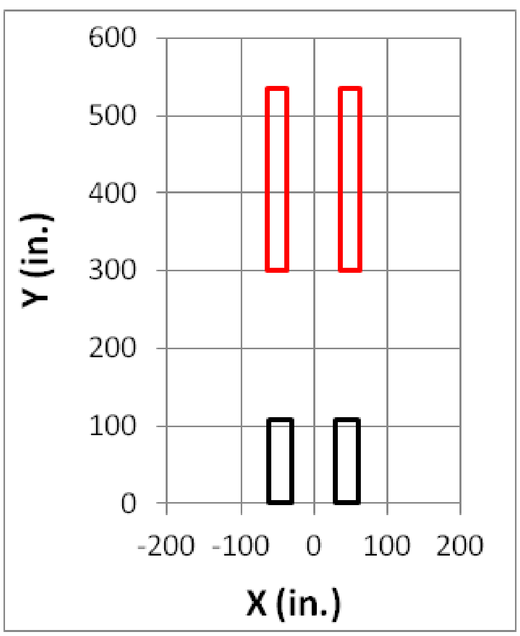


Figure 4. Load Case 2 (ice edge at y = 0). Note that the bridge footprint is represented in black, and the tank sled's are in red.

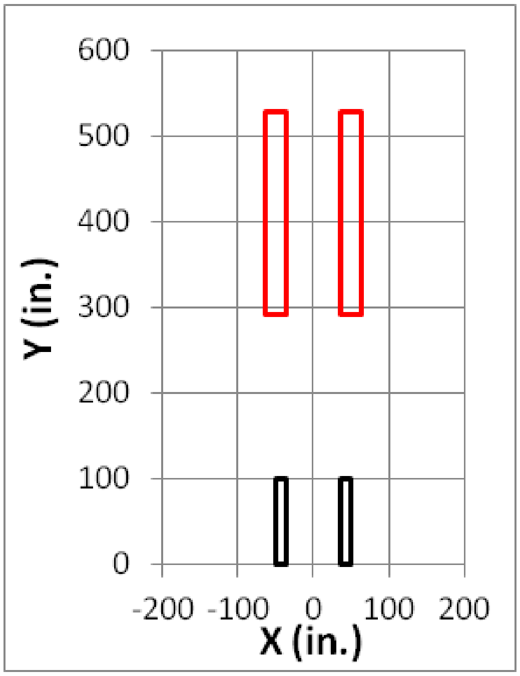


Table 2. Load distribution at the edge of a semi-infinite ice sheet.

Load Distribution (Total Load in lbf)	Tractor			Tank Sled		
	Each Tread Area (in. × in.)	Distance Between Treads (in.)	Contact Pressure (psi)	Each Tread Area (in. × in.)	Distance Between Treads (in.)	Contact Pressure (psi)
1 (73627)	30 × 108	62	6.38	36 × 236	54	1.90
2 (78231)	14 × 100	72	16.38	36 × 236	54	1.90

We ran the resulting load distributions in Table 2 through an analytical model to calculate maximum stresses and deflections for comparison against maximum allowable values. The process involved applying Nevel's (1965) method to the scenario for determining results of loads applied by uniform pressure over a rectangular area situated at the edge of a floating ice sheet, Figure 5. The resulting values are the maximum deflection and the maximum moment presented in non-dimensional form at the origin (x = 0, y = 0 in Figure 5). The methodology involves combining positive and negative loads of different rectangular areas to arrive at load distributions consistent with those defined in Figures 3 and 4. These results are used to determine maximum deflection and maximum tensile stress at the origin by superposing the results of two and four loads applied over two and four rectangular areas, respectively (Figures 6 and 7).

Figure 5. Uniform positive pressure over a rectangular area at the edge of a semi–infinite floating ice sheet, as presented by Nevel (1965).

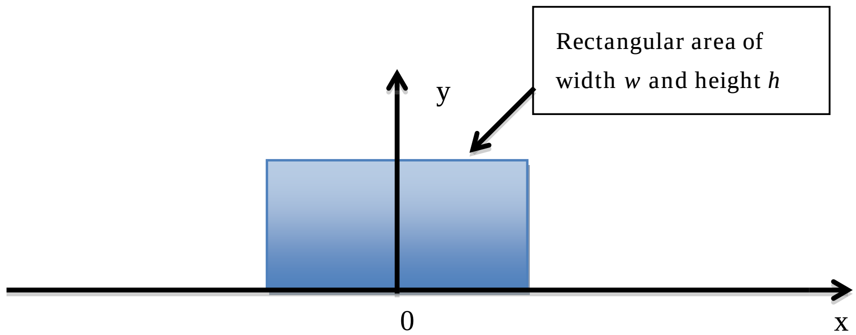


Figure 6. Positive (blue) and negative (white) uniform pressures applied over two rectangular areas.

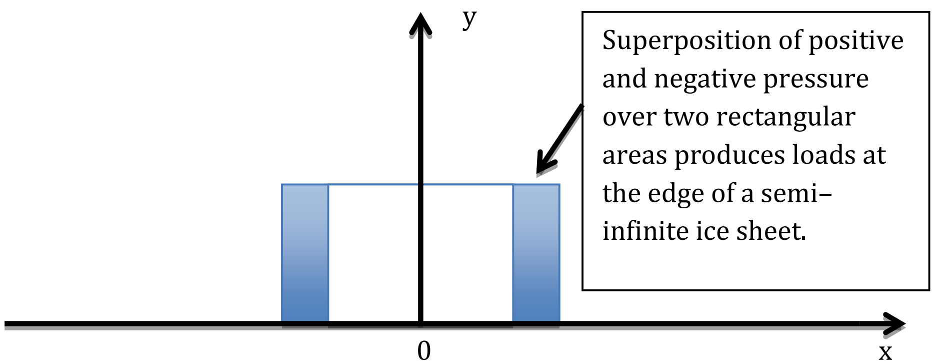
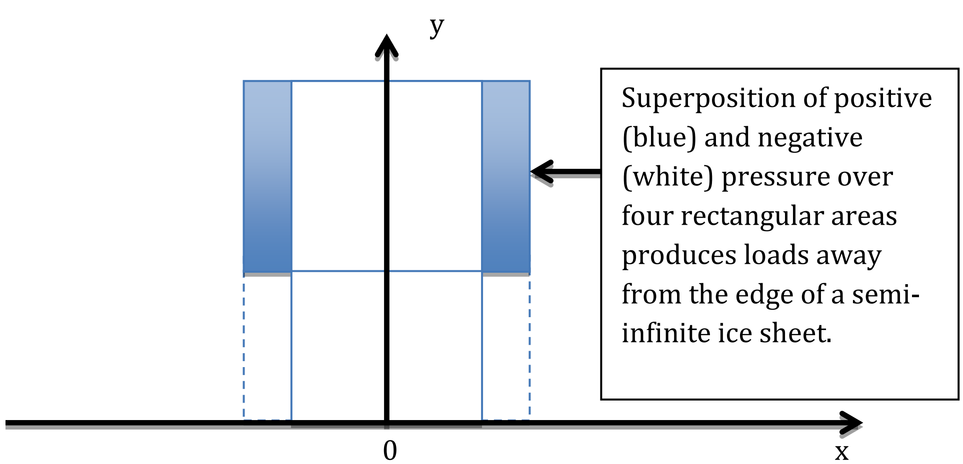


Figure 7. Application of positive and negative pressures to develop the representative load configuration.



We calculated the maximum deflection and the maximum tensile stress in a spreadsheet in which the contributions of various loads (uniform pressures over rectangular areas illustrated above) are superposed to obtain the results at the origin. Though the maximum deflection is not affected by the distribution of a load, the maximum tensile stress depends strongly on the load distribution. When we conducted a finite element analysis (Appendix B), we found that the maximum stress is located at the bottom edge of the ice sheet under the middle of a tractor tread. At that location, the stresses are 3% higher than those at the origin as calculated by the method presented above. Thus, the tensile stress calculated at the origin is increased by 3% to obtain the estimate of maximum tensile stresses presented below in Tables 3 and 4.

Table 3. Maximum deflection and maximum tensile stress for load distribution 1. (Green box: failure criterion is met; red box: failure criterion is not met.)

Load Distribution 1	Period				
	1	2	3	4	
Temperature (°C)	≤−27	−27 < x ≤ −20	−20 < x ≤ −10	−10 < x ≤ −4	
Elastic Modulus (GPa)	4.1	2.7	1.7	1.1	
Allowable Stress (kPa)	338	321	300	207	
Criterion 1: Maximum deflection < freeboard					
Ice Thickness (m)	Maximum Deflections (m)				Freeboard (m)
1.00	0.057	0.068	0.082	0.098	0.100
1.25	0.043	0.052	0.063	0.075	0.125
1.50	0.034	0.041	0.050	0.060	0.150
1.75	0.028	0.033	0.041	0.049	0.175
2.00	0.023	0.028	0.034	0.041	0.200
Criterion 2: Maximum tensile stress < allowable stress					
Ice Thickness (m)	Maximum Stress (kPa)				
1.00	684	639	585	531	
1.25	484	455	423	392	
1.50	365	343	341	328	
1.75	285	269	267	251	
2.00	230	218	211	204	

Table 4. Maximum deflection and maximum tensile stress for load distribution 2. (Green box: failure criterion is met; red box: failure criterion is not met).

Load Distribution 2	Period				
	1	2	3	4	
Temperature (°C)	≤−27	−27 < x ≤ −20	−20 < x ≤ −10	−10 < x ≤ −4	
Elastic Modulus (GPa)	4.1	2.7	1.7	1.1	
Allowable Stress (kPa)	338	321	300	207	
Criterion 1: Maximum deflection < freeboard					
Ice Thickness (m)	Maximum Deflections (m)				Freeboard (m)
1.00	0.063	0.075	0.09	0.108	0.100
1.25	0.047	0.056	0.068	0.082	0.125
1.50	0.037	0.044	0.054	0.065	0.150
1.75	0.030	0.036	0.044	0.053	0.175
2.00	0.025	0.030	0.037	0.045	0.200
Criterion 2: Maximum tensile stress < allowable stress					
Ice Thickness (m)	Maximum Stress (kPa)				
1.00	768	715	662	606	
1.25	545	512	474	441	
1.50	408	386	359	344	
1.75	317	302	291	264	
2.00	254	242	235	222	

Tables 3 and 4 present the calculated maximum deflection and stress for load distributions 1 and 2, respectively, for various ice thicknesses during the four ice condition periods defined in Table 1. The green boxes indicate that particular safety criterion has been met whereas the red boxes indicate that the safety criterion has not been met. **Both safety criteria must be satisfied** to place a load safely on a floating ice sheet. The results in Table 3 and 4 show that it is safe to cross a narrow lead without a bridge and a wide lead with bridge during Periods 1–3 when the ice thickness is equal to or greater than 1.75 m and for all periods when the ice thickness is equal to or greater than 2.00 m. Figures 8–11 show maximum deflection and maximum tensile stress versus ice thickness during the different periods. **In the cases of crossing small cracks or when using the CRB for wide leads, it is required that multi-trailer trains disconnect and tow a single sled at a time across each crack or across the CRB.**

Figure 8. For load distribution 1, maximum deflection versus ice thickness during four temperature periods.

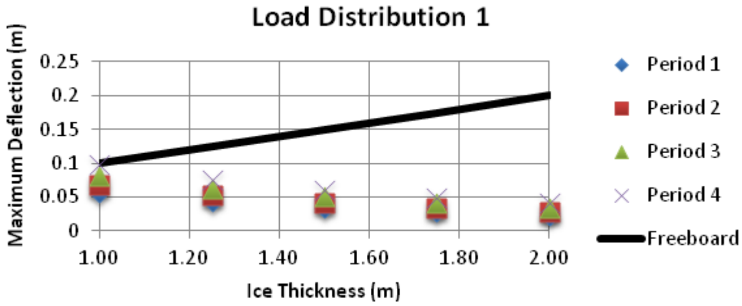


Figure 9. For load distribution 1, maximum tensile stress versus ice thickness during four temperature periods.

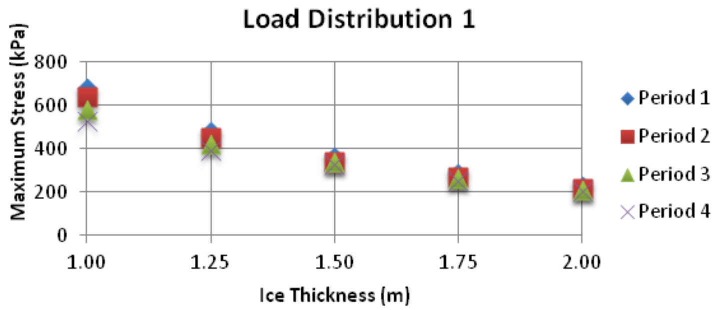


Figure 10. For load distribution 2, maximum deflection versus ice thickness during four temperature periods.

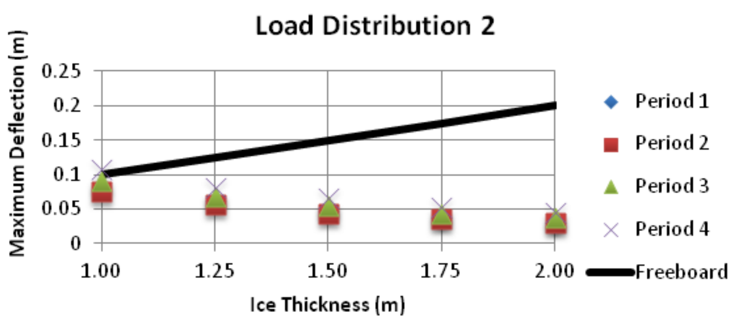
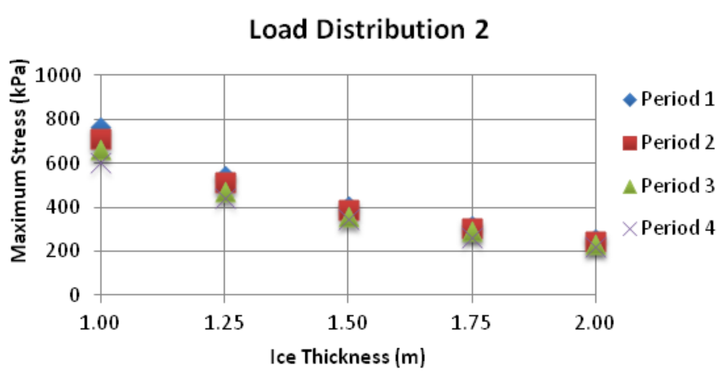


Figure 11. For load distribution 2, maximum tensile stress versus ice thickness during four temperature periods.



5 Evaluating Traverse Loads in the Middle of an Infinite Ice Sheet

We calculated the safe sea-ice thickness required to support loads on an essentially infinite (un-cracked) ice sheet by using the results of Wyman (1950), who presented a closed-form elastic analysis of a circular load over a plate on an elastic foundation. The contribution of each circular load is superposed to obtain the deflection and the stress at the origin.

Determining whether or not a load scenario meets the definition of an infinite ice sheet is based on the characteristic length of a floating ice sheet. The characteristic length depends mainly on the elastic modulus and the ice thickness, and it is most often between 10 and 20 times the ice thickness, depending on the ice temperature. When the MPT load (tractor and tank sled) is more than 5–6 times the characteristic length from a lead, the ice sheet can be considered as an infinite ice sheet. The criteria for safe placement of a load on an infinite ice sheet are the same as for a semi-infinite ice sheet; however, the point where maximum deflection and maximum tensile stress occur is usually at the bottom of the ice sheet, centrally located under the treads of the tractor or tank sled rather than at the ice edge.

The procedure to calculate maximum deflection and maximum tensile stress is to replace the loads having rectangular footprints by a series of loads of uniform pressure over circular areas, shown in Figure 12. The tread load is distributed such that the total magnitude of the load is the same. By shifting the origin at different points, we found that maximum stress occurs when the origin is located between the third and fourth load (circular plates) from the bottom of Figure 12. Table 5 presents the results of these calculations, which indicate that a 40 in. thick ice sheet can support the load during periods 1–3 whereas a 50 in. thick ice sheet can safely carry the load during periods 1–4. A 30 in. thick ice sheet can safely carry the load during period 1. Practically, it is unlikely a traverse will ever encounter an ice sheet entirely free of cracks. This case is presented to illustrate the differences in ice strength properties between unbroken and cracked sheets and also to provide thickness requirements for regions of unbroken ice that a traverse may wish to use to navigate between cracked areas that lack sufficient thickness.

Note that the infinite ice sheet evaluation procedure used here for the Marble Point Traverse fleet is consistent with the method used by Bjella and Weale (2012) for the entire McMurdo vehicle fleet operating on sea ice.

Figure 12. A load having rectangular footprints as a series of loads over circular areas.

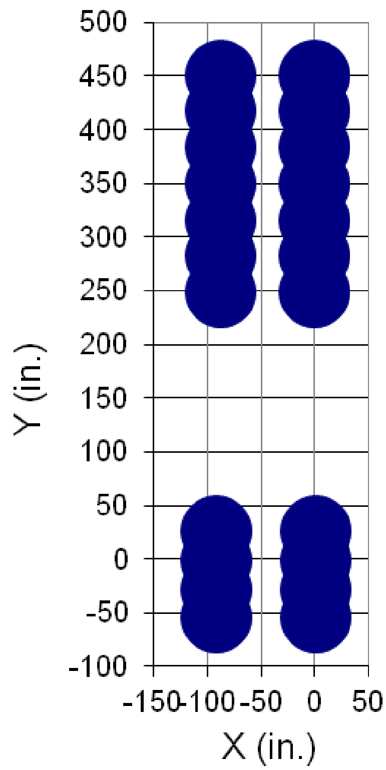


Table 5. Maximum deflection and maximum tensile stress for a series of circular loads far away from any lead. (Green box: failure criterion is met; red box: failure criterion is not met.)

Series of circular loads	Period				
	1	2	3	4	
Temperature (°C)	≤−27	−27 < x ≤ −20	−20 < x ≤ −10	−10 < x ≤ −4	
Elastic Modulus (psi)	5.89×10^5	5.89×10^5	5.89×10^5	5.89×10^5	
Allowable Stress (psi)	49	46.5	43.5	30	
Criterion 1: Maximum deflection < freeboard					
Ice Thickness (in.)	Maximum Deflections (in.)				Freeboard (in.)
30	1.673	1.901	2.106	2.233	3
40	1.146	1.309	1.456	1.548	4
50	0.847	0.971	1.083	1.153	5
Criterion 2: Maximum tensile stress < allowable stress					
Ice Thickness (in.)	Maximum Stress (psi)				
30	38.6	47.1	54.4	58.6	
40	24.8	30.4	35.2	38.0	
50	17.4	21.5	24.9	26.9	

6 Summary

An over-sea-ice traverse from McMurdo Station routinely resupplies Marble Point Camp. This traverse requires tractor trains to travel over large segments of both multi-year and, at times, first-year sea ice, which can contain both narrow and wide leads (cracks). This report determined the ice thicknesses required for the resupply traverse to safely operate on both cracked and un-cracked (infinite) ice sheets during the four periods.

Wide leads require a bridge, and we based our safety parameters for that condition on the CRB. Results presented in this paper are based on analyses of homogeneous sea-ice strength properties. Therefore, we recommend that the MPT stays clear of regions where there is an isolated multi-year floe embedded in first-year ice as our results are not valid for that condition.

The analyses considered a Caterpillar Challenger 95E tractor with attached Fassi crane (41,000 lb combined weight) towing a single 3000 gal. steel tank sled full of fuel (32,370 lb) because multi-trailer trains must reconfigure to tow only a single sled at a time across wide or narrow leads. Based on an engineering cut sheet received from NZAP, we determined that the CRB had a clear span of 13 ft and weighed 9208 lb. Note that a structural analysis of the CRB was not within the scope of this report.

The analyses considered all four periods of sea-ice temperatures, and Table 6 presents the results. We found that that for all load cases and sea-ice periods, tensile stresses in the ice govern the ice thickness requirements. Thus, any operations that require vehicles, trailers, or sleds to remain in a single location for an extended period of time (greater than an hour) require freeboard monitoring. The vehicles, trailers, or sleds must be relocated once the available freeboard is within 1 in. of the ice surface.

Table 6. Safe sea-ice operating criteria for Marble Point Traverse vehicles.

Load Case[a,b,c,d]	Required Ice Thickness (m)	Sea-ice Period—Required Min. Temp.(°C)			
		1 (≤−27)	2 (≤−20)	3 (≤−10)	4 (≤−4)
1—Narrow Lead	1.75	✓	✓	✓	✗
1—Narrow Lead	2.00	✓	✓	✓	✓
2—Bridge Required	1.75	✓	✓	✓	✗
2—Bridge Required	2.00	✓	✓	✓	✓
3—Infinite Ice Sheet	0.75	✓	✗	✗	✗
3—Infinite Ice Sheet	1.00	✓	✓	✓	✗
3—Infinite Ice Sheet	1.25	✓	✓	✓	✓

[a] All load cases presented here are governed by maximum tensile stresses in the ice.

[b] For all load cases in all periods: it is essential to monitor freeboard for any stationary period. Fleet vehicles, sleds, and the bridge must be relocated once the freeboard is within 1 in. of the ice surface.

[c] Maximum navigable lead width = 4m = maximum Cape Roberts Bridge span.

[d] Multi-trailer trains must disconnect and tow a single sled at a time across narrow cracks and across the Cape Roberts Bridge.

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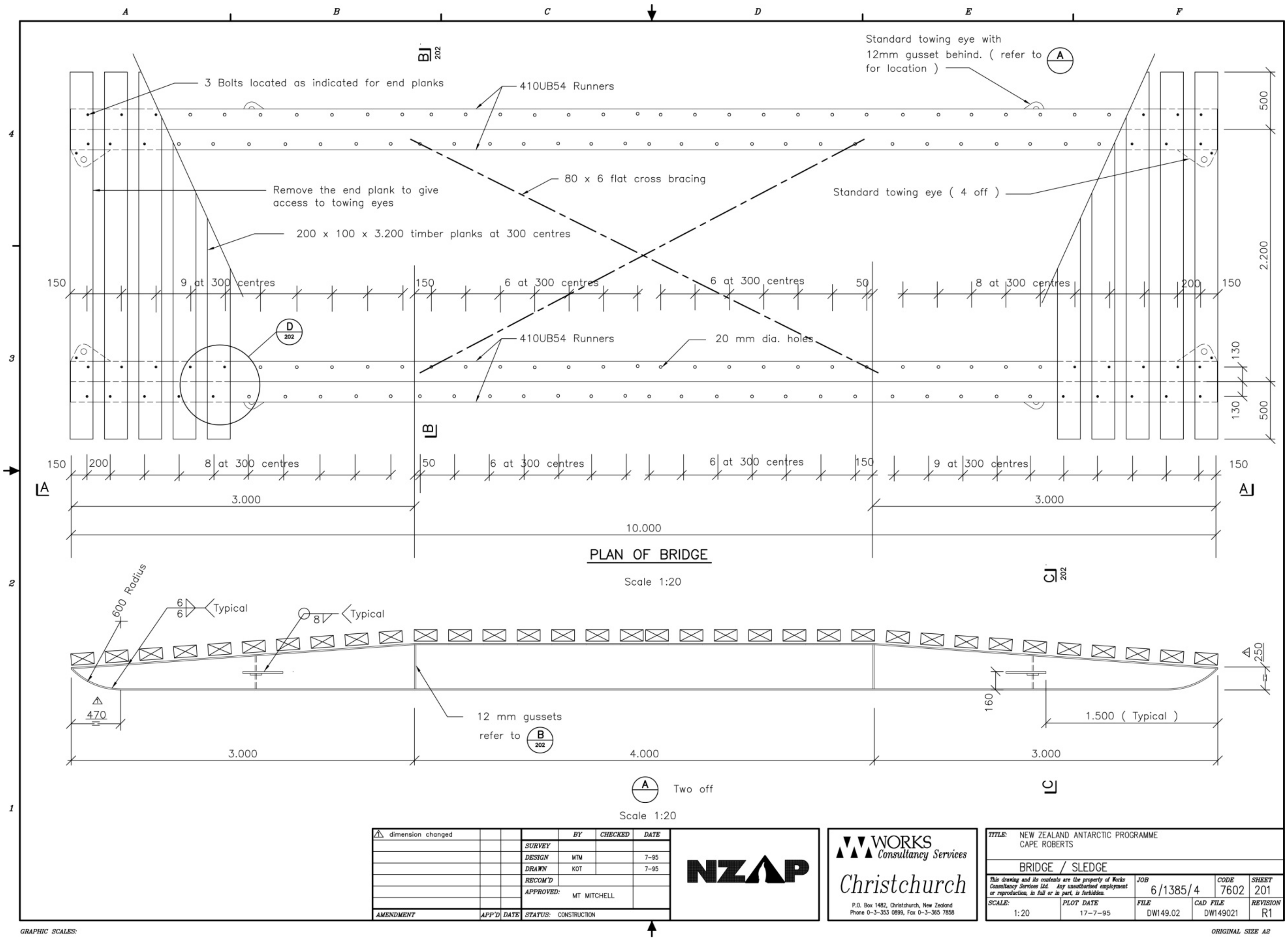
Appendix A: Cape Roberts Bridge Cut Sheets



3 Bolts located as indicated for end planks
410UB54 Runners
Standard towing eye with 12mm gusset behind. (refer to A for location)
Remove the end plank to give access to towing eyes
80 x 6 flat cross bracing
Standard towing eye (4 off)
200 x 100 x 3.200 timber planks at 300 centres
9 at 300 centres
6 at 300 centres
8 at 300 centres
20 mm dia. holes
3.000
10.000
PLAN OF BRIDGE
Scale 1:20
600 Radius
Typical
12 mm gussets refer to B
1.500 (Typical)
4.000
A Two off
Scale 1:20
dimension changed
AMENDMENT
APP'D
DATE
BY
CHECKED
SURVEY
DESIGN MTM 7-95
DRAWN KOT 7-95
RECOM'D
APPROVED: MT MITCHELL
STATUS: CONSTRUCTION
NZAP
WORKS Consultancy Services
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P.O. Box 1482, Christchurch, New Zealand Phone 0-3-353 0899, Fax 0-3-365 7858
TITLE: NEW ZEALAND ANTARCTIC PROGRAMME CAPE ROBERTS
BRIDGE / SLEDGE
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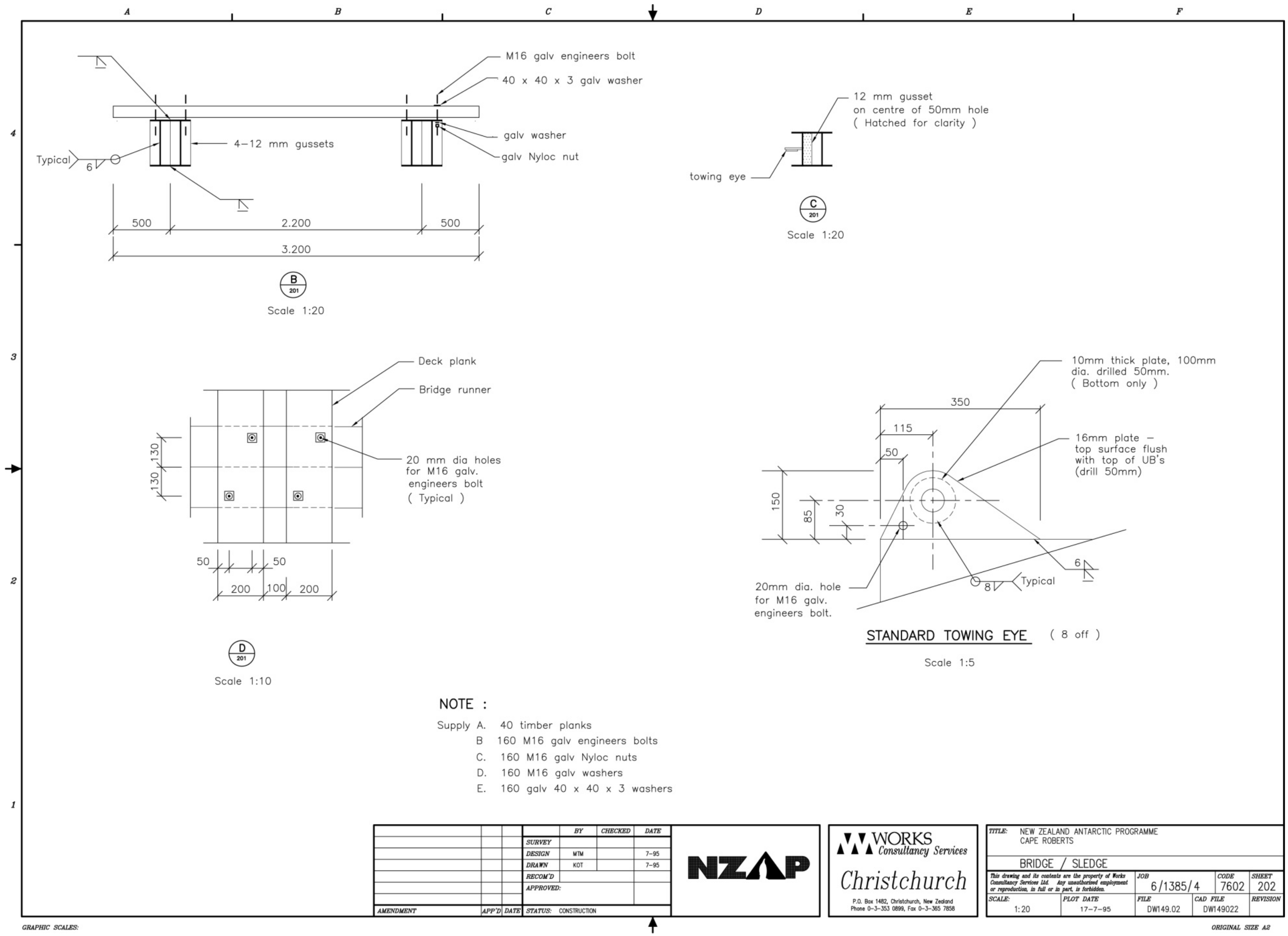
JOB 6/1385/4
CODE 7602
SHEET 201
SCALE: 1:20
PLOT DATE 17-7-95
FILE DW149.02
CAD FILE DW149021
REVISION R1
GRAPHIC SCALES:
ORIGINAL SIZE A2


M16 galv engineers bolt
40 x 40 x 3 galv washer
4–12 mm gussets
galv washer
galv Nyloc nut
Typical
6
500
2.200
500
3.200
B
201
Scale 1:20
12 mm gusset
on centre of 50mm hole
(Hatched for clarity)
towing eye
C
201
Scale 1:20
Deck plank
Bridge runner
20 mm dia holes
for M16 galv.
engineers bolt
(Typical)
130
130
50
50
200
100
200
D
201
Scale 1:10
10mm thick plate, 100mm
dia. drilled 50mm.
(Bottom only)
350
115
50
16mm plate –
top surface flush
with top of UB's
(drill 50mm)
150
85
30
20mm dia. hole
for M16 galv.
engineers bolt.
6
8
Typical
STANDARD TOWING EYE (8 off)
Scale 1:5
NOTE :
Supply A. 40 timber planks
B 160 M16 galv engineers bolts
C. 160 M16 galv Nyloc nuts
D. 160 M16 galv washers
E. 160 galv 40 x 40 x 3 washers
BY CHECKED DATE
SURVEY
DESIGN MTM 7-95
DRAWN KOT 7-95
RECOM'D
APPROVED:
AMENDMENT APP'D DATE
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SCALE: 1:20
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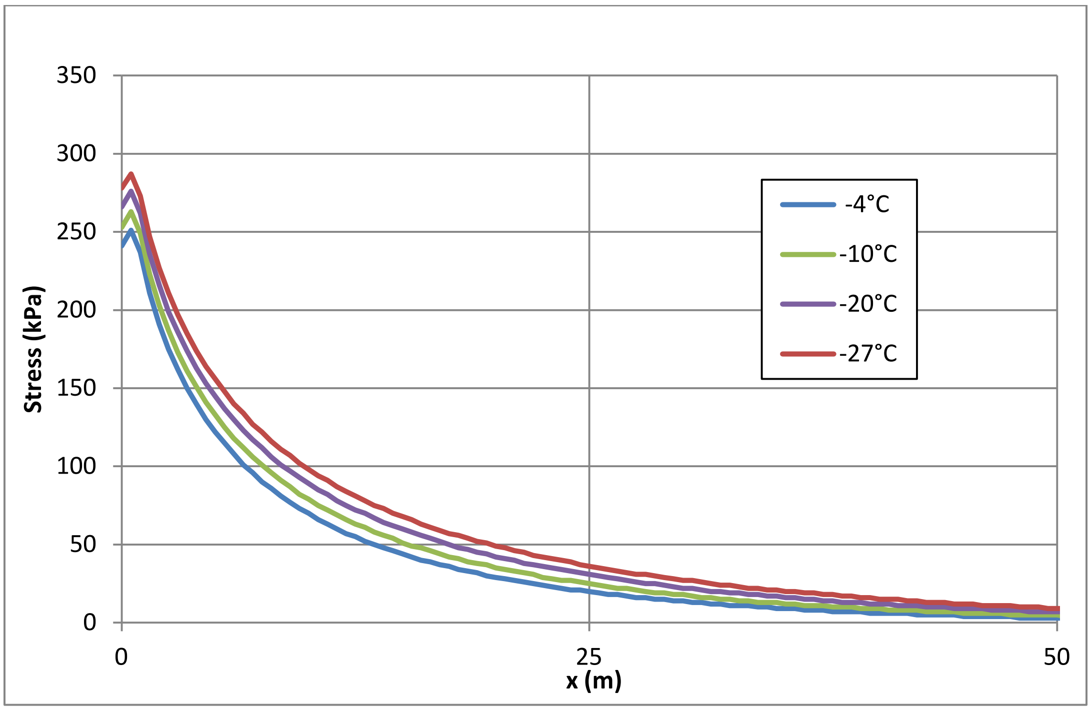
FILE DW149.02
CAD FILE DW149022
REVISION
GRAPHIC SCALES:
ORIGINAL SIZE A2

Appendix B: FEM Results for Maximum Stresses at the Bottom of a Semi-Infinite Ice Sheet

Below is a plot of tensile stress at the bottom of an ice sheet along the edge (y = 0). The total load of 312,500 N (70,252 lbf) on the ice sheet is distributed over rectangular areas (Figures 5–7) at and near the edge of ice sheet to represent track pressure of vehicles.



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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

14. ABSTRACT

The United States Antarctic Program's Antarctic Infrastructure and Logistics Program within the National Science Foundation's Division of Polar Programs operates an over-sea-ice traverse from McMurdo Station to routinely resupply Marble Point Camp. The traverse requires that heavy tractor trains travel over large segments of sea ice that can contain both narrow and wide leads (cracks).

For this effort, we determined the ice thicknesses required for the resupply traverse to safely operate on both cracked and un-cracked (infinite) ice sheets during each of the four periods of sea-ice temperatures at McMurdo Station. Results presented in this report are valid for first-year sea ice only, and we recommend that the Marble Point Traverse stays clear of regions where there is an isolated multi-year floe embedded in first-year ice. Our analyses considered a 41,000 lb Caterpillar Challenger 95E tractor with attached Fassi crane towing a single 3000 gal. steel tank sled full of fuel (32,370 lb). Wide leads require use of a bridge, and thus we also consider the load case where a 9208 lb bridge is used to cross open leads up to 13 ft wide. We derived our results from a combination of finite element analysis (ice with leads) and closed-form solutions (semi-infinite and infinite ice sheets).

15. SUBJECT TERMS

Bridging Sea Ice	Heavy Traverses on Sea Ice	Sea Ice Strength
EPOLAR	Sea Ice Safety	Semi-infinite Sea Ice
	NSF	USAP

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